Long-range Transport of Pollutants to the West Coast of North America

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Abstract
Several research studies have demonstrated that Asian anthropogenic emissions significantly impact the concentration of a number of air pollutants measured in Western North America.

Other studies have indicated that this contribution to the "background" levels of air pollutants may rise, impacting human and ecosystem health to a greater extent than at present. Clearly air management plans need to take these potential changes into account.

Results of a literature survey of long range transport measurements and mechanisms are summarized. The effects of Global Change are considered. Potential impacts on airshed management are discussed.

Introduction
A number of research studies have demonstrated that Asian anthropogenic emissions significantly impact the concentration of several pollutants measured in Western North America. Additional studies have indicated that as Asian economies expand, the "background" level of a these pollutants can be expected to rise, affecting human and ecosystem health to a greater extent than at present. Clearly air management plans need to take this into account. This paper highlights selected findings from the literature, focusing on rising tropospheric ozone. Internet addresses are provided where possible.

Many Pollutants Travel Long Distances in the Atmosphere
Analysis of pollution concentrations in various media such as sediment,[1] snow, fish and birds have long cast suspicion that persistent organic pollutants[2], polychlorobiphenyl [3], pesticides[4], nitrates and sulphates[5] and heavy metals such as mercury[6] among others are being transported across the Pacific.

Certain air pollution events have been observed, investigated and demonstrated to be of Asian origin. The prevailing mid-latitude westerlies provide an effective mechanism for transport from Asia to North America. Dan Jaffe of the University of Washington, for example, has used isentropic back-trajectories to demonstrate that a broad range of atmospheric species observed at the Cheeka Peak observatory on the Olympic Peninsula originated in Asia.[9]. Most of the aerosols and gases that are born on the westerlies are invisible. In April 1998, however, the arrival of fine particulate from a massive dust storm in western China caught media attention. These large dust events are visible on satellite imagery, providing a visual model of intercontinental transport. More can be found on this particular event at http://capita.wustl.edu/Asia-FarEast. Analysis of additional dust events can be found in Merrill[7] and in Xiao.[8]

There have been several large-scale campaigns to investigate the long-range transport process. The Pacific Exploratory Mission (PEM)-West campaigns of 1991 and 1994,[10] the ACE-Asia (aerosol Characterization Experiment – Asia),[11] the TRACE-P experiment (Transport and Chemical Evolution over the Pacific),[12] Intercontinental Transport and Chemical Transformation of Anthropogenic Pollution (ITCT), SOLAS (Surface Ocean Lower Atmosphere Study)[13] and PHOBEA (Photochemical Ozone Budget of the Eastern North Pacific Atmosphere)[14] have all been conducted to detail the properties, evolution and transport of pollutants and the attendant effects on the ecosystem. Even so, observational data remains limited. The next large experiment being planned is INTEX-NA (Intercontinental Chemical Transport Experiment—North America) scheduled for summer 2004 and spring 2006[15]. This experiment is designed to build a dataset intended to quantify the inflow, outflow, and transformations of chemicals over North America. Of specific interest are aerosols, the major greenhouse gases, and ozone and its precursors (hydrocarbons, NO_x and HO_x).

"Background Levels" ofOzone and its Precursors
In airshed management, background air pollution levels can be defined either as average levels measured in "pristine" areas of the globe (such as the arctic) or simply as those levels typical of the air entering the airshed. To this background are added local or regional emissions—those which presumably managers might be able to take some action to control. In a practical sense then, background might also be defined as those beyond the ability of air managers to control.

Background Values Have Been Rising

There is a substantial background of ozone present in the lower troposphere that has both a stratospheric and photochemical tropospheric origin which varies spatially and seasonally.[16] Ozone was first measured in the mid-1800s. At that time average daily maximum ozone readings in both Europe and near the Great Lakes typically fell in the range of 17 to 23 ppbv. Lefohn et al[17] have concluded that typical background values in these areas have approximately doubled, and they show that even locations considered pristine (such as Point Barrow, Alaska) now have much higher averages than those of 100 years ago. While some scientists have suggested that ozone is in fact increasing everywhere by at least 1% per year, there is certainly global variability, and some of the apparent increase may in fact be due to changes in instrumentation.[18] While the rate of increase may be uncertain, there is no doubt that background values of ozone have been increasing in Western North America. The most recent estimates suggest that typical background values for the west coast of the US during the April to October period are in the range of 30 plus or minus 5 ppbv.[19]

Sources of Background Ozone

Ozone concentrations in remote areas vary through the year with significant photochemical production in the summer months. There are also significant episodes of elevated ozone observed in the spring. Monks[20] has provided an excellent review of this spring maximum. There is much literature devoted to explanation of the mechanisms that bring ozone formed in the stratosphere into the troposphere where it may, under certain meteorological circumstances, mix to the surface.[21] Mechanisms that can transport ozone from the surface into the mid to upper troposphere, and then to the surface again at some distant point, are less well explained. Ozone has a long lifetime in the atmosphere (~months), but the ocean has been found to be a net ozone destroying region, and can be considered to be a buffer against anthropogenic ozone increases[21]. NO_x has a short lifetime (~1 day) and could not be expected to cross the Pacific, Kotchenruther et al[21] describe a chemical mechanism whereby longer lived PAN, however, can cross the ocean to contribute significantly in the springtime ozone production of Northeastern Pacific. It was noted earlier that ozone concentrations at remote locations such as Point Barrow have been rising. This is especially so in spring. It is probable that the cause of this increase in background levels is the increase in anthropic emissions at locations throughout the northern hemisphere[23], with background levels entering the coast of Western North America affected most strongly by increases in Asian emissions.

Effect of Economic Expansion in Asia

The Asian economy has been expanding rapidly, with a corresponding dramatic increase in the amount of fossil fuels consumed. Emissions controls employed in the burning of these fuels has been minimal (other than in Japan). From the mid-1970s to the 1990s the emissions from both NO_x and SO_2 increased at an average of ~5%/year.[24] This economic expansion is forecast to continue for at least the next decade. Model calculations have been made to investigate the probable impact of this increase in Asian ozone and its precursors on the background values of these contaminants entering western North America. Jacob et al indicate an increase in monthly mean O3 concentrations of 2 to 6 ppbv by 2010 (more than offsetting 25% of the domestic reductions in anthropogenic emissions of NOx and hydrocarbons in the western United States),[25] while Jonson et al. note this is, in fact, a global problem with surface ozone rising 8 to 10% despite emission reduction efforts in North America and Europe.[26] It would seem that global increases will make local efforts to reduce ozone and its precursors more difficult. Lafohn goes so far as to suggest that rising global ozone background levels will "affect the ability of the US and Canada to attain their 8-hour ozone standards. The Canadian country-wide ozone standard (CWS) of 0.065 ppm for the 4th highest 8-hour ozone concentrations averaged over three years will be almost impossible to attain."[27] It may be that this is over-stated, however, as episodes with an Asian origin are primarily spring-time events with 8-hour concentrations, which to date do not exceed .065 ppm. In fact, the CWS standard of .065 ppm has not been exceeded at the western Canadian background monitoring location at Saturna Island at any time in the period 1983-2000, nor was the standard exceeded at any ambient observing site (National Air Pollution Surveillance site) in western Canada during the period 1997-2000.[29]

Impact on global warming

The Intergovernmental Panel on Climate Change notes the increasing importance of total tropospheric ozone as a radiation-forcing agent. In fact, it may soon rival methane in importance. *The following are two excerpts from the IPCC's third assessment report*[30]:

From Working Group 1 (The Scientific Basis) Technical Summary:
(http://www.ipcc.ch/pub/wg1TARtechsum.pdf)

"The global average radiative forcing due to increases in tropospheric ozone since pre-industrial times is estimated to have enhanced the anthropogenic greenhouse gas forcing by 0.35 W/m2. This makes tropospheric ozone the third most important greenhouse gas after CO2 and CH4.

Ozone concentrations respond relatively quickly to changes in the emissions of pollutants. On the basis of limited observations and several modelling studies, tropospheric ozone is estimated to have increased by about 35% since the Pre-industrial Era, with some regions experiencing larger and some with smaller increases. There have been few observed increases in ozone concentrations in the global troposphere since the mid-1980s at most of the few remote locations where it is regularly measured. The lack of observed increase over North America and Europe is related to the lack of a sustained increase in ozone-precursor emissions from those continents. However, some Asian stations indicate a possible rise in tropospheric ozone, which could be related to the increase in East Asian emissions."

From Working Group 2 (Impacts, Adaptation and Vulnerability) technical summary:
(http://www.ipcc.ch/pub/wg2TARtechsum.pdf)

"In 2000, the IPCC completed a Special Report on Emissions Scenarios (SRES) which consider the period 1990 to 2100 and include a range of socioeconomic assumptions (e.g. global population and gross domestic product). Their implications for other aspects of global change also have been calculated. For example, mean ground-level ozone concentrations in July over the industrialized continents of the northern hemisphere are projected to rise from 40 ppb in 2000 to more than 70 ppb in 2100. By comparison, the clean-air standard is below 80 ppb. Peak levels of ozone in local smog events could be many times higher."

What to do?

North American efforts to reduce the emissions of the precursors of ozone have been aimed at reducing the magnitude of 1-hour episodes. This has been fairly successful, but recent studies have led us to understand that human health is affected at much lower ozone concentrations than previously suspected, leading Canadian and US governments to develop new standards based on longer averaging times with lower threshold values. Some have suggested that cumulative exposures should also be considered in airshed management.[31] The lower the threshold of ozone concentrations used in defining acceptable air quality, the more important a rising background ozone level becomes. It can't be denied that local efforts can reduce both cumulative exposure and the magnitude of episodes, so these efforts must continue. It would be desirable if Asian countries (in addition to Japan) would chose to implement similar emission reduction strategies, but as this seems unlikely, perhaps there is hope that local or international efforts will be made to reduce Asian greenhouse gas emissions, with reduction of ozone precursors arising as a co-benefit.

Acknowledgements

The author wishes to acknowledge the summary by Wilkening et al.,[32] which pointed to a number of the sources cited in this summary. Readers may also turn to "The Aloya Consensus Statement on Long-Range Atmospheric Transport and Effects of Contaminants in the North Pacific Region"[33] for a relevant conference summary and a recent list of contacts in the field. Internet links are offered when known, but note that some of these sites require a subscription to access the journals.

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